Problem of Transshipment in Travel Forecasting

Model of Tour Structures

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The concept of the transshipment of goods has not been widely incorporated into models for transportation planning. A model with transshipment should recognize that a whole shipment could be transported in two or more stages involving intermediate points (transshipment points) between the origin and the final destination. The database containing data from the Ontario, Canada, Commercial Vehicle Survey is one of the few databases that contains substantial transshipment information. The analysis of the Ontario Commercial Vehicle Survey first focused on commodities and their origin–destination facilities and defined terminals and warehouses as possible transshipment locations. Analysis revealed that any commodity was likely to be transshipped through either a truck terminal or a warehouse. Eight tour structures could be ascertained from the database, with each structure differing in the order and number of transshipment points and previous customers. A choice model of those tour structures was built. Factors such as commodity type, origin–destination facility type, truck type, distance, and shipment size were significant, depending on the structure.

The transshipment problem as it pertains to the freight forecasting components of travel models involves a choice of destinations, given that a whole shipment is transported in two or more stages. In a two-stage process, for example, the first stage might consist of transport of a product from the point of production to a transshipment point, and a second stage would then consist of transport of those goods from the transshipment point to a point of consumption. A large number of shipments pass through transshipment points during their journey, until they reach their final destination. Transshipment is used for many reasons: a shipment from a producer might be split into multiple, smaller shipments at a transshipment facility (e.g., a terminal, warehouse, or distribution center) with several ultimate destinations. Alternatively, a shipment might be taken to its consumer indirectly because other shipments in the truck must be delivered first. Transshipment has strong implications for the provision of public infrastructure, because the routing of shipments on roads or other public facilities is not necessarily by the least-cost path between the first origin and the last destination. Many shipments travel by longer, less direct routes. Most available data on commodity shipments within a single country identify the first origins and the last destinations but not any transshipment points along the way. The Commercial Vehicle Survey, provided by the Ministry of Transportation of Ontario, Canada, proved to have particularly useful data on transshipment.

This paper focuses on development of a tour structure model in which shipments either pass through one or more intermediate points (a transshipment point or some other consumer) or go directly from the point of production to the point of consumption. The model targets the specific distinctiveness of establishments and the trip characteristics. Factors such as location, origin facility type, destination facility type, commodity type, truck type, distances, and shipment size are most likely to affect the decision of how an industry might deliver its products to another establishment.

PREVIOUS WORK

Transshipment has been studied extensively by researchers in logistics, but almost all of these studies relate to improving the actions of an individual firm rather than the net effect of many firms acting within a whole economy. The reasons for transshipment could be to change the means of transport, to combine small shipments into a large shipment or vice versa, or to store a shipment for a period of time. Freight modeling is increasingly giving attention to the fact that the development of both production systems and logistics is having a fundamental influence on the amount and structure of freight demand. In this context, a trend toward experimental microscopic models of commercial transport has come up in recent years. These new models put an emphasis on the actors, such as shippers and forwarders.

The lack of a transshipment component within most freight forecasting models is likely due to the extreme variety of transshipment decisions, which depend on products, markets, and local economic factors. Although it may be possible theoretically for a freight model to mimic a wide range of decision processes, it would be far simpler to develop a transshipment relationship empirically, provided a suitably comprehensive database could be obtained. An empirical model has the additional advantages of (*a*) aggregating experiences across closely related products and industries, (*b*) providing a result that can be immediately incorporated into freight models, and (*c*) validating existing theory and conventional wisdom.

Tour-based models, which have recently become popular for passenger travel forecasting (*1*), are sequential models from an origin

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Transportation Research Record: Journal of the Transportation Research Board, No. 2255, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 48–57.
DOI: 10.3141/2255-06

to multiple destinations that take into account the time and space constraints among the trips of the same tour. This means that the model considers the origin of the trip and then the next stop, which may be the workplace or, in the case of freight, a warehouse, terminal, or retail store. Hunt and Stefan developed a tour-based model for the Calgary, Alberta, Canada, region that accounts for truck routes involving all types of commercial vehicles as well as all sectors of the economy (*2*). They used a Monte Carlo technique to assign attributes to each of the tours. These attributes included tour purpose, vehicle type, purpose of the next stop, location of the next stop, and duration at the next stop. They established the probabilities used in the microsimulation process using logit models estimated with choice data collected in local surveys. Donnelly developed a model capable of representing the interactions of agents and elements for freight demand and the factors that influence those interactions (*3*). The components of the model include economic drivers, modal alternatives, transshipment, exports, imports, shipment generation, destination and vehicle choice, and finally, tour optimization. The resulting model was used in a freight simulation with traditional traffic assignment methods.

As indicated by Hunt and Stefan, tour structure models would have particular advantages in a microsimulation (*2*). A microsimulation provides a means of modeling behavioral patterns exhibiting high degrees of variability. The interaction between shippers and carriers is an excellent example of such behavior. Boerkamps and van Binsbergen discussed the theory and applications of GoodTrip, which was one of the early commodity-based microsimulation efforts (*4*). This model estimates goods flows and urban freight traffic and its impacts. It determines the logistical performance and environmental effects of alternatives for urban goods distributions, emphasizing the concentration of goods flows, destinations, and routes.

Wisetjindawat et al. developed a commodity-based model to explain a commodity's movements as an outcome of its flow through several freight agents in a supply chain (*5*). The model reproduces each firm individually and covers just the steps of commodity generation and distribution. Generated commodities are linked from the point of production to the point of consumption according to the attractiveness of each production point, resulting in commodity flows from firm to firm over the entire area according to their relationships in supply chains.

Ben-Akiva et al. developed a model to estimate the transport costs, shipment size frequency, and mode distribution to predict regional and interregional freight movement in Norway (*6*). The model determines the optimal transshipment location for each type or tour chain and origin–destination zone. The shipment size and tour chain are then finally determined from all available options for a firm-to-firm flow to determine the one with the lowest cost, which becomes the transport chain choice.

Although it may not be as logistically detailed as studies cited earlier, the multistate regional model of the Mississippi Valley Freight Coalition is the stepping-off point for this research (*7*). The Mississippi Valley Freight Coalition model is a microsimulation in which the probability of any of eight tour structures is obtained from historical percentages that vary only by commodity. However, the tour structures allow the model to determine the number of separate trips between the producer and consumer, to find suitable transshipment locations among known warehouses and terminals, to ascertain trip lengths, and to sequence the trips correctly for dynamic traffic assignments.

ONTARIO COMMERCIAL VEHICLE SURVEY

The Commercial Vehicle Survey Program in Ontario, Canada, involves surveys of intercity trucking activity. Its objective is to obtain information on freight flows on the provincial highway system. The Commercial Vehicle Survey is a roadside-intercept survey of highway trucking activity. The survey collects information on origins, destinations, routes used, goods carried, weights (vehicle, axle, and commodity), vehicle dimensions, and driver characteristics. The survey is conducted at truck inspection stations, rest areas, road maintenance yards, and border crossing plazas. The last Commercial Vehicle Survey was completed between 2005 and 2007, but the data set from that survey has not yet been publicly released in sufficient detail for transshipment analysis. Data from an earlier survey, conducted between 1999 and 2001, are available on request. This study used data from that survey, which are the latest data that Ontario was willing to share. That survey collected more than 40,000 samples.

The Ontario Commercial Vehicle Survey commodity coding is done by using the Standard Classification of Transported Goods, so the data are consistent with those in databases in the United States.

The difference between commodities is important to the analysis of the possible transshipment points made during a journey. Although the Ontario Commercial Vehicle Survey contains more than 40,000 samples, just 29,822 samples are for trucks that contain commodities. As mentioned earlier, the Commercial Vehicle Survey commodities are coded by the Standard Classification of Transported Goods, but Ontario also produced more aggregated categories of the commodities, as follows:

1. Agricultural products,
2. Food,
3. Minerals and products,
4. Petroleum and products,
5. Chemicals and products,
6. Wood and products,
7. Metals and products,
8. Machinery and electrical,
9. Manufactured products,
10. Transportation,
11. Waste and scrap, and
12. Shipping containers returning empty.

The Commercial Vehicle Survey uses the following trip facilities:

1. Truck terminal: your carrier,
2. Truck terminal: another carrier,
3. Rail terminal,
4. Marine terminal,
5. Airport terminal,
6. Primary producer,
7. Manufacturer,
8. Warehouse or distribution center,
9. Retail outlet,
10. Commercial or office building,
11. Construction sites,
12. Residences,
13. Home,
14. Waste facilities, and
15. Recreational sites.

TABLE 1 Origin–Destination Facility Matrix

Trip Origin Facility	Trip Destination Facility: Truck Terminal–Your Carrier	Truck Terminal–Another Carrier	Rail Terminal	Marine Terminal	Airport Terminal	Primary Producer	Manufacturer
Truck terminal–your carrier	5,634	250	23	23	18	120	1,211
Truck terminal–another carrier	143	189	4	6	4	11	83
Rail terminal	15	1	17	3	0	1	40
Marine terminal	19	4	2	10	0	5	29
Airport terminal	8	1	0	0	45	0	7
Primary producer	127	19	9	9	5	305	699
Manufacturer	1,048	124	66	36	18	170	4,766
Warehouse or distribution center	533	61	19	23	22	93	782
Retail outlet	96	8	0	5	2	20	72
Commercial or office building	6	1	1	1	1	2	3
Construction sites	19	2	0	1	0	1	5
Residences	11	0	0	0	0	4	5
Home	10	0	0	0	1	3	16
Waste facilities	10	1	0	0	0	4	49
Recreational sites	10	0	0	0	0	3	1

The truck types considered by the Commercial Vehicle Survey are as follows:

Type 1. Tractor and trailer,
Type 2. Tractor and two trailers,
Type 3. Tractor and three trailers,
Type 4. Straight truck,
Type 5. Straight truck and trailer,
Type 6. Tractor only, and
Type 95. Other.

PRELIMINARY ANALYSIS

First-Cut Data Analysis

The majority of the trucks contain manufactured products, transportation, wood products, and foods, with the leading commodity being manufactured products (16.07%). The trip facilities are critical indicators of the transshipment locations. The leading origin facilities were manufacturer, truck terminal (driver's carrier), and warehouse or distribution center. Terminals and warehouse and distribution centers are considered possible transshipment locations, which resulted in 52% of origins being transshipment locations. As with the origin facilities, the majority (54%) of the destination facilities were terminals or warehouses. A warehouse at the destination end may or may not be a transshipment point, depending on its proximity to the point of consumption. If more than 50% of origins and more than 50% of destinations are at transshipment points, then a large percentage of all truck trips involve transshipment at one end or the other. An origin–destination facility matrix is essential for understanding commodity shipment behaviors. Table 1 shows the origin–destination facility patterns found in the Ontario Commercial Vehicle Survey.

The persuasiveness of transshipment is evident from the numbers of trips in Table 1. However, the most interesting result in Table 1 is that many trips have both their origin and their destination at a terminal or a warehouse (36%). Given that neither end is a production location or a consumption location, these shipments must involve at least three legs, at least two of which are not (in all likelihood) captured explicitly in the data set. Note that a trip with a transshipment location at just one end could also have three or more legs but would most likely involve just two legs.

The analysis of possible transshipment points can also be done by looking at the interaction between the trip facilities, either origin or destination, and the type of commodity carried by the truck. In this case it is possible to identify those commodities that are most likely to be transshipped. Table 2 shows a summary of the number of trips by commodity at the destination end. Table 2 reveals that most of the commodities involve a transshipment location. A certain degree of symmetry seems to exist in transshipment across most commodities, even though the reasons for transshipment at the destination would likely differ from the reasons for transshipment at the origin. Agricultural products, manufactured products, and transportation are commodities that are the most likely to be transshipped. Note that Table 2 shows only the trips at the destination end and that their origin could be from another transshipment location. Indeed, on the basis of the commercial vehicle survey, significant numbers of trips originated at a transshipment location, either a truck terminal or a warehouse, meaning that many trips involve three legs. During this analysis it was found that manufactured goods are largely carried from or to transshipment points, with a total of 83% being transshipped at the origin and a total of 72% being transshipped at the destination.

The distance traveled by a truck is an important characteristic for determining specific transshipment points along its route. Distance can be analyzed in different ways. That is, trip length could vary by commodity, facility type at the origin end, facility type at the destination end, or some combination. Any trip with a transshipment point is likely to have a much shorter length than any other trips covering the same distance between the point of production and the point of consumption. Analysis revealed that agricultural products

Warehouse or Distribution Center	Retail Outlet	Commercial or Office Building	Construction Sites	Residences	Home	Waste Facilities	Recreational Sites
1,086	561	31	69	34	8	30	14
100	50	0	2	0	0	7	0
20	22	0	0	1	0	3	0
31	13	1	2	0	0	2	0
7	3	1	0	0	0	0	2
418	250	8	142	16	5	20	15
2,667	950	35	115	26	10	59	12
2,316	1,181	36	43	59	17	22	3
125	202	3	10	20	6	12	3
13	3	31	1	1	1	2	0
13	12	1	18	1	1	6	0
14	11	0	3	76	3	2	2
10	5	2	2	22	136	3	2
6	5	0	0	0	0	57	0
7	2	1	0	0	2	0	9

and manufactured products were among the commodities that have longer trip distances. Furthermore, it was found that transshipment occurs more frequently for longer trips.

The available literature suggests a need for additional analysis of data on transshipment that considers common behavioral mechanisms across firms within a whole economy. Furthermore, a potential need for models that may be conveniently incorporated into existing travel demand forecasting frameworks exists. The reasons for choosing logit analysis for transshipment are that the database with data from the Ontario Commercial Vehicle Survey contains many potentially interesting variables, and a statistical analysis method that can find salient effects is needed. Furthermore, a choice model is natural, elementary, and interpretable. Once it is calibrated, it can be used for forecasting.

Tour-Based Approach Development

Figure 1 illustrates some alternative tour structures. Three possible structures are present in the simple diagram in Figure 1:

- Freight is moved from the production location to where it will be consumed by the end consumer;
- Between the producer and the end consumer, one contact point where the freight is transferred from the producer to the end consumer is present; and
- One or more additional points for consolidating or deconsolidating a shipment between the producer and the end consumer are present.

TABLE 2 Truck Trips by Commodity and Destination Facility

	Trip Destination Facility					
	Truck Terminal– Your Carrier	Truck Terminal– Another Carrier	Warehouse or Distribution Center	Retail Outlet	Commercial or Office Building	Construction Sites
Agricultural products	354	35	518	357	2	4
Food	736	59	1,163	727	7	3
Minerals and products	381	20	316	157	15	235
Petroleum and products	173	15	153	214	4	21
Chemicals and products	666	54	678	212	14	7
Wood and products	853	86	921	321	17	32
Metals and products	519	52	583	180	11	44
Machinery and electrical	393	27	371	161	17	41
Manufactured products	1,857	186	1,287	565	51	17
Transportation	1,252	92	630	348	13	5
Waste and scrap	170	11	74	22	2	1

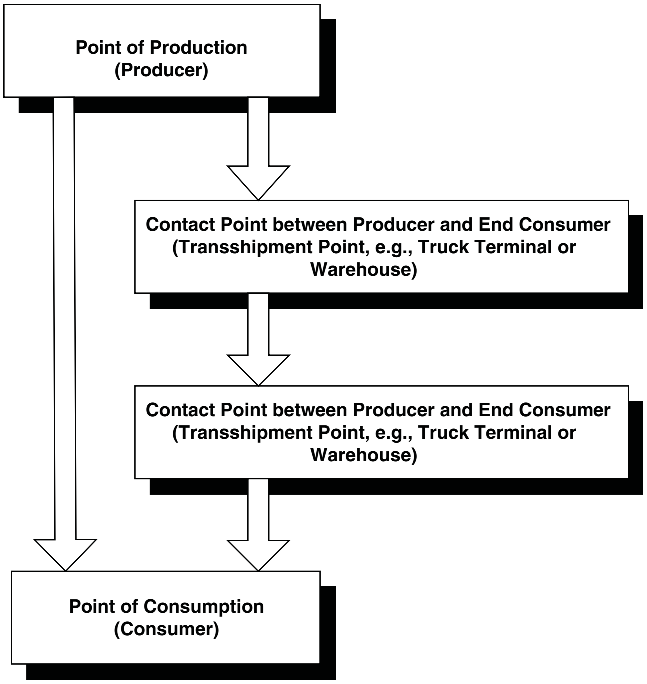

FIGURE 1 Tour-based structure modeling.

For analysis purposes the supply chain exists as long as the commodity remains intact or separately identifiable. Once the commodity is used as a raw material in another product or process, the supply chain is terminated. Because the analysis is concerned with the delivery of a particular shipment, the structures do not include any trips in which the truck would be empty or on a backhaul.

The tour-based approach developed in this paper accounts for all the commodities provided in the data set. The establishments that are used in the tour generation are segregated into three facility type categories. The facility types to be considered are producer, consumer, and warehouse (the warehouse facility type also includes truck terminals). The facility types considered include those that serve as possible transshipment locations, but in this case, only truck terminals and not the "other" terminals provided by the Ontario Commercial Vehicle Survey are considered.

Tour Structures

The previous analysis revealed that most commodities would likely be involved on a supply chain of at least three legs. This involves its point of origin (from its producer), at least two transshipment locations (truck terminals or warehouses), and finally, its final destination or consumer. The next analysis involves a fuller range of possible tour structures. Figure 2 summarizes those structures that could be discerned from the Ontario Commercial Vehicle Survey.

The tour structures were created on the basis of information about commodity origin–destination and trip origin–destination on the Ontario Commercial Vehicle Survey, with recognition that the trip and commodity may not travel between the same locations. The longer arrows in Figure 2 (or the dashes later in the text) indicate trips that have distinctively longer distances than any other trips in the structure. Full information was available only for trip origins and trip destinations, so it was necessary to assume that the producer was nearer the commodity origin and the last consumer was nearer the commodity destination. For those tour structures that have three legs, the middle two establishments were taken to be the trip origin and the trip destination, whereas the outer establishments were taken to be the commodity origin and the commodity destination. For those tours of exactly two legs, either the commodity origin and the trip origin or the commodity destination and the trip destination were the same. Finally, the simplest case was producer–consumer, in which the commodity origin was the same as the trip origin and the commodity destination was the same as the trip destination.

As shown in Figure 2, eight different tour structures could be detected. The tour structure analysis revealed that producer-warehouse-warehouse-consumer was the structure with the largest number of trips, followed by producer-warehouse–consumer. As mentioned earlier, the tour structures with dashes indicate trips longer in distance than any other trips in the structure. For example, about one-sixth as many structures of producer–warehouse-consumer than of producer-warehouse–consumer were detected in the database. This means that transshipment is most likely to occur near the origin. For each of the commodities, the producer-warehouse-warehouse-consumer structure had the greatest probability. For the cases of manufactured products and transportation, producer-warehouse-warehouse-consumer structures account for 74% of all structures. Meanwhile, agricultural products have origins at farms or elevators; and their destinations are places such as elevators, feedlots, ethanol plants, and food-processing plants; however, the probability that they reach their final destinations directly from their origin does not seem to occur often, with such trips accounting for just 14% of shipments. The only commodity group that shows a relatively high probability of being shipped directly from its origin to its destination is minerals and products (36%). Long tour structures with multiple consumers are rare in all cases.

TOUR STRUCTURE MODEL

The Ontario Commercial Vehicle Survey contains information on origin–destination, routes used, goods carried, weights (vehicle, axle, and commodity), vehicle dimensions, and driver characteristics. Among all the data obtained from the database, previous analyses revealed that commodity types, facility types, truck types, distance, and shipment size were significant variables to be considered in model development (*8, 9*).

This model should describe the choice of a specific tour structure on the basis of selected attributes. Because eight discrete tour structures were detected, a multinomial logit technique is applied. Given the fact the commodity type, facility types, truck types, distance, and shipment size were all important attributes and were significant in previous analyses, they should be considered for inclusion in the deterministic utility equation of the logit model.

The model must recognize that the movement of agricultural commodities differs from the movement of manufactured commodities. All agricultural products have their origins at farms or elevators, whereas their destinations are other elevators, ports, other storage facilities, retail outlets, or processors. The location of these might be in the same municipality or state or province, so distances might be close, if the destination is in an agricultural state or province.

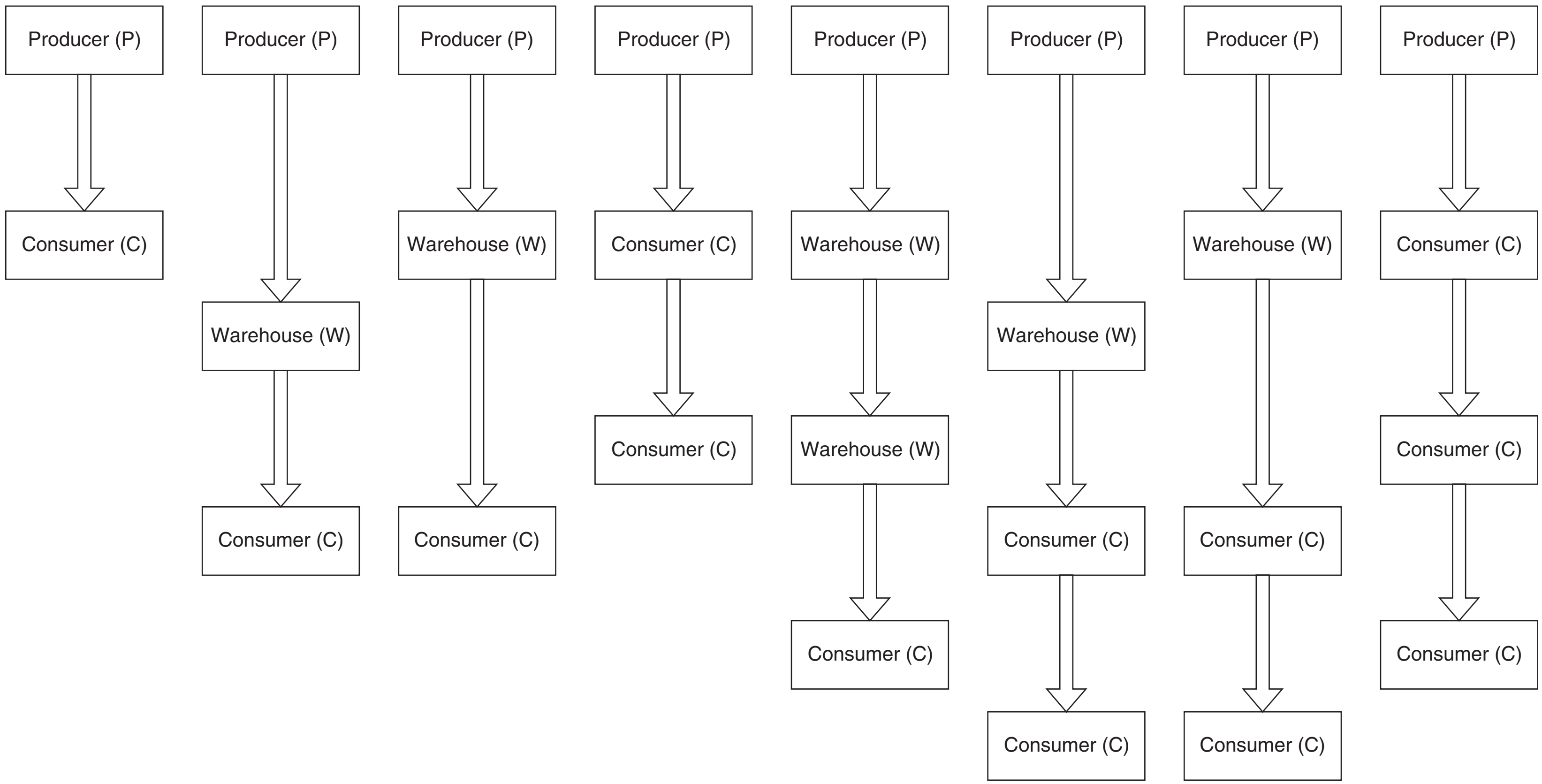

FIGURE 2 All tour structures found in Ontario Commercial Vehicle Survey.

However, manufactured products might be transported into assembly locations before they reach a retail store. The distance between the location of a manufactured product and the destination (e.g., a retail store) might be somewhat longer than that for agricultural products. The shipment size also plays a significant role when transshipment locations are considered. Bigger shipments might point to different destinations, and those might consider a separate transshipment location to split them.

Formally, for a shipment that originates at any given producer, the utility of a tour structure (U_{tour}) is specified as

$$U_{tour} = ASC_{tour} + \beta_{commodity} + \beta_{origin\ facility} - \beta_{destination\ facility} + \beta_{truck\ type} + \beta_1(\text{total distance}) + \beta_2(\text{shipment size}) \quad (1)$$

where

ASC_{tour} = alternative specific constant for tour structure,
$\beta_{commodity}$ = coefficient for commodity type,
$\beta_{origin\ facility}$ = coefficient for origin facility type,
$\beta_{destination\ facility}$ = coefficient for destination facility type,
$\beta_{truck\ type}$ = coefficient for truck type,
β_1 = coefficient for distance between producer and consumer,
β_2 = coefficient for shipment size,
distance = distance between producer and consumer (mi), and
shipment size = shipment size (lb).

Dummy variables for each of the attributes except distance and shipment size were used to estimate the model. That is, the model assigns a value for each specific commodity type, facility type, and truck type. Great-circle distances between the commodity origin and destination facilities were obtained on the basis of their coordinates (latitude and longitude), although the distance between the trip origin and the trip destination was calculated over the road within the database.

Table 3 shows the estimated coefficients and their *t*-scores for Equation 1.

The model was reestimated several times to obtain the coefficients that best predict what is happening in the database. Overall, most of the individual coefficients have *t*-scores indicating that the estimated values were significant for the tour structures. Some coefficients (for example, $\beta_{residences}$) did not have significant values for any structure. Some variables were excluded because of the requirement for dummy variables. The initial log likelihood was −36,015.101, whereas the final log likelihood was −23,054.016. Although the log likelihood did not have a huge drop, it is acceptable. The rho-square value obtained was 0.311.

For this model, the alternative specific constants varied from each other, with the highest value being for the tour structure producer-warehouse–consumer (0.06), as expected. This particular constant reflects the fact that most of the shipments pass through transshipment points before they reach their final destination and that the origin and the transshipment locations are within a short distance. The specific alternative with the lowest value of the constant was the tour structure producer-consumer-consumer-consumer, with a constant of −4.25 indicating that this structure is unlikely to be chosen.

Different commodities, different origin–destination facility types, and different truck types exist; however, some of them were not sig-

TABLE 3 Coefficients for Tour Structure Choice Model

		Tour Structure		
Attribute or Constant	Coefficient	P-C Value (*t*-score)	P-W–C Value (*t*-score)	P–W-C Value (*t*-score)
Alternative specific constant	ASC	−0.232 (−4.54)	0.06 (6.22)	−0.308 (8.15)
Commodities	$\beta_{agricultural\ products}$	—	—	—
	β_{food}	0.418 (3.12)	0.561 (4.53)	0.684 (3.42)
	$\beta_{minerals\ \&\ products}$	−0.907 (−6.23)	−0.585 (−7.33)	−0.625 (−5.69)
	$\beta_{petroleum\ \&\ products}$	1.01 (3.68)	0.689 (3.01)	0.835 (3.69)
	$\beta_{chemicals\ \&\ products}$	0.676 (4.63)	0.348 (2.95)	0.467 (3.01)
	$\beta_{wood\ \&\ products}$	—	—	—
	$\beta_{metals\ \&\ products}$	—	—	—
	$\beta_{machinery\ \&\ electricals}$	—	—	—
	$\beta_{manufactured\ products}$	−1.11 (−16.18)	—	—
	$\beta_{transportation}$	—	—	—
Origin facility type	$\beta_{primary\ producer}$	—	—	—
	$\beta_{manufacturer}$	−0.158 (−2.65)	0.029 (2.79)	0.039 (2.55)
Destination facility type	$\beta_{retail\ outlet}$	0.281 (2.78)	0.102 (2.76)	0.291 (2.61)
	$\beta_{commercial\ or\ office\ building}$	—	—	—
	$\beta_{construction\ sites}$	−0.461 (−2.64)	—	—
	$\beta_{residences}$	—	—	—
Truck type	$\beta_{tractor\ \&\ trailer}$	−1.15 (−3.04)	−1.11 (−3.02)	−1.03 (−3.16)
	$\beta_{tractor\ \&\ 2\ trailers}$	—	—	—
	$\beta_{straight\ truck}$	—	—	—
	$\beta_{straight\ truck\ \&\ trailer}$	—	—	—
Distance	β_1	−0.000394 (−3.4)	−0.000393 (−3.89)	−0.000471 (−3.59)
Shipment size	β_2	−0.0000202 (2.89)	0.0000187 (2.45)	0.0000198 (2.76)

NOTE: P = producer; C = consumer; W = warehouse; — = no data exist.

nificant in some of the tour structures. For example, agricultural products do not have a coefficient for tour structure producer–consumer. Thus these commodities will not influence the choice of this particular tour structure. That is not the case for the tour structure producer-warehouse-warehouse-consumer, for which the coefficient for agricultural products was 0.209. The reason why the producer–consumer alternative does not have a value whereas producer-warehouse-warehouse-consumer does is that many agricultural products (e.g., wheat and corn) have their origins at farms or elevators and many of those products need to be stored at elevators before they reach their final destination (e.g., feedlots, ethanol plants, and food-processing plants). After those agricultural products have been dried and stored, they might be split into different shipments at a transshipment location to reach their final destination.

Another interesting result of this model relates to the coefficient for manufactured products. The producer–consumer alternative for manufactured products obtained a value of −1.11 for this coefficient. However, the *t*-score was −16.18, which strongly indicates that manufactured products will not go directly from the producer to the consumer. The tour structure producer-warehouse-warehouse-consumer for manufactured products obtained a coefficient of 0.246 with a *t*-score of 5.16, indicating that most manufactured products will have a transshipment location. The remaining tour structures did not have a significant value for manufactured products, and thus, this particular commodity did not influence their choice.

A better idea of how different commodities tend toward different tour structures can be gleaned from Figure 3. The order of the bars from left to right in Figure 3 is the same as the order from top to bottom shown at the right of Figure 3. Two commodity groups, metals and machinery, have been removed because they did not have coefficients that varied significantly by tour structure. The fact that some commodities mostly have odds ratios less than 1 and other commodities mostly have odds ratios greater than 1 is due to the effects of other variables in the model that interact with commodities. The relative heights of the bars within a single commodity are the most interesting finding. The tour structures in Figure 3 have been ordered from left to right roughly by complexity. Some relationships are immediately evident. Food, chemical, and transportation products tend toward having tour structures without warehousing but with multiple customers. Agricultural and manufactured products show an interesting tendency toward tour structures with multiple warehouses (or elevators). The data suggest that any commodity could have any tour structure.

Total distance is an important factor for each of the tour structures involving transshipment locations. For example, producer-consumer-consumer-consumer and producer-consumer-consumer structures had the largest-magnitude β_1 of about 0.0004, indicating that the chance that longer shipments will use these particular tour structures that do not contain any warehousing is less. Shipment size also has some influence on whether transshipment is chosen, as it can be seen that the coefficients are consistent in sign and magnitude for all structures except producer–consumer, for which shipment size is inversely related to the probability that this structure will be chosen.

The tour structure model as is estimates the utility function for a tour structure on the basis of several variables, including the commodity. However, it is entirely possible that different commodities might not follow the same patterns. To see if this is the case, separate models

P-C-C Value (*t*-score)	P-W-W-C Value (*t*-score)	P-W–C-C Value (*t*-score)	P–W-C-C Value (*t*-score)	P-C-C-C Value (*t*-score)
−1.31 (−15.32)	0	−0.402 (−17.41)	−2.088 (−13.84)	−4.25 (−12.12)
−0.400 (−2.79)	0.209 (3.41)	−0.332 (−2.98)	−0.498 (−3.01)	−0.419 (−2.95)
1.062 (6.84)	0.871 (6.87)	0.888 (6.83)	0859 (6.90)	1.111 (6.77)
−0.857 (−6.03)	−0.943 (−11.29)	−0.468 (−2.85)	−0.678 (−2.87)	−1.394 (−1.93)
—	0.674 (2.67)	1.033 (3.58)	0.925 (3.62)	—
0.963 (5.95)	0.709 (5.07)	0.879 (5.58)	0.579 (5.63)	1.008 (5.52)
—	0.086 (2.02)	−0.611 (−3.73)	−0.797 (−3.77)	—
—	—	—	—	—
—	—	—	—	—
—	0.246 (5.16)	—	—	—
0.637 (2.79)	0.227 (4.21)	0.451 (4.12)	0.313 (4.04)	0.667 (2.51)
—	—	—	—	—
−0.121 (−2.32)	−0.170 (−1.97)	−0.759 (−3.39)	−0.909 (−3.32)	−0.888 (−3.35)
0.265 (2.97)	0.221 (2.57)	0.229 (2.68)	0.201 (2.63)	0.278 (2.80)
—	—	—	—	—
−1.486 (−2.11)	—	−1.64 (−2.20)	−1.72 (−2.16)	—
—	—	—	—	—
−1.11 (−3.03)	−1.017 (−2.86)	−1.13 (−2.82)	−1.17 (−2.76)	−1.162 (−3.08)
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
−0.000379 (−3.51)	−0.000166 (−1.95)	−0.0000897 (−2.27)	−0.0000901 (−2.23)	−0.000397 (−3.24)
0.0000181 (2.88)	0.0000196 (2.98)	0.0000192 (2.09)	0.0000191 (2.05)	0.0000190 (2.76)

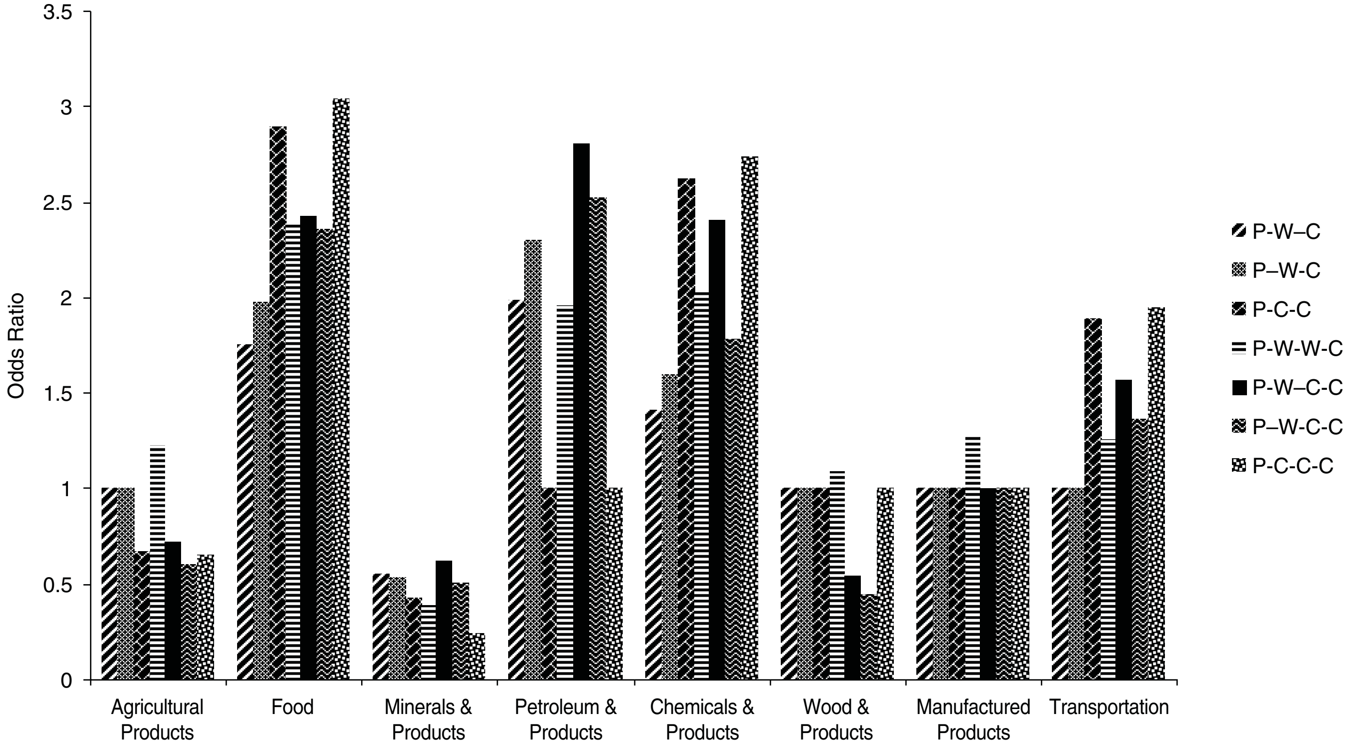

FIGURE 3 Odds ratios for selected commodities.

were estimated for food and for manufactured products. The model for food was reestimated several times to obtain the variables that best predict what is happening for this particular commodity. The model ended up being reduced to just the variables of tour structure, distance, and shipment size. The model for manufactured products included the same variables but also included some truck types. An acceptable drop in the log likelihood occurred for both of the models (e.g., −8,559.902 to −3,691.307 for manufactured products); however, the rho-square value obtained did not show much of an improvement (e.g., it went from 0.311 for the original tour structure model to 0.335 for the manufactured products model).

The tour structure model, as opposed to the commodity models, contains more variables, which potentially makes it sensitive to a wider range of inputs. For this reason, use of the original tour structure model containing all commodities would be a better approach for applications such as the Mississippi Valley Freight Coalition freight model.

CONCLUSION

The transshipment model developed in the study described in this paper forecasts tour structure choice. The model was developed with data from the Ontario Commercial Vehicle Survey, which uses the same commodity coding used in the U.S. Commodity Flow Survey. However, the model developed used aggregated commodity types obtained from the Ontario Commercial Vehicle Survey. Significant coefficients were found for commodity type, origin facility type, destination facility type, truck type, shipment size, and distance between the commodity's origin and destination, depending on the structure.

The Ontario Commercial Vehicle Survey contains information on truck trips that could be used to develop a choice model of tour structures. However, the number of survey samples in the database is too small to build a model for highly detailed commodities. Some of the results of the model could be transferable to the United States or other countries. In particular, the prevalent tour structures as well as some of the significant coefficients could be used when the results are transferred.

A tour structure model opens up the possibility of development of a model of transshipment location choice. Such a model would lead to an origin–destination truck table in which each leg of each tour would be separately represented.

Future work should permit the use of other forms of logit models, such as mixed logit or nested logit models, to ascertain other patterns in the database.

The tour structure model developed in the present study is suitable for both conventional and microsimulation freight forecasting models, particularly for statewide and multistate applications, such as the Mississippi Valley Freight Coalition region. As is, the tour structure model may not be sufficiently sensitive for inclusion in forecasting models for urban regions because of the tendency for Ontario to capture principally long-haul trips in its survey.

ACKNOWLEDGMENTS

This study was funded by the National Center for Freight and Infrastructure Research and Education, a university research center of the U.S. Department of Transportation. The database analyzed in this study was provided by the Ontario Ministry of Transportation.

REFERENCES

1. Miller, E., M. J. Roorda, and J. A. Carrasco. A Tour-Based Model of Travel Mode Choice. Presented at 10th International Conference on Travel Behavior Research, 2003.
2. Hunt, J. D. Tour-Based Microsimulation of Urban Commercial Vehicle Movements in Calgary, Alberta, Canada: Case Example. In *Conference Proceedings 40: Freight Demand Modeling: Tools for Public-Sector Decision Making,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 61–71.
3. Donnelly, R. A Hybrid Microsimulation Model of Freight Flows. In *City Logistics V* (E. Taniguchi and R. Thompson, eds.), Institute of City Logistics, Kyoto, Japan, 2007, pp. 235–246.
4. Boerkamps, J. H. K., and A. van Binsbergen. GoodTrip—A New Approach for Modeling and Evaluation of Urban Goods Distribution. Presented at Urban Transport Systems 2nd KFB-Research Conference, Lund, Sweden. 1999. http://www.ersa.org/ersaconfs/ersa03/cdrom/papers/173.pdf.
5. Wisetjindawat, W., K. Sano, and S. Matsumoto. Commodity Distribution Model Incorporating Spatial Interactions for Urban Freight Movement. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1966,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 41–50.
6. Ben-Akiva, M., G. de Jong, and J. Baak. *Method Report: Logistics Model in the Norwegian Freight Model System.* Significance, The Hague, Netherlands, 2008.
7. Horowitz, A. Microsimulation of Commodity Flow in the Mississippi Valley Region. Innovations in Freight Demand Modeling and Data. SHRP 2 Symposium. Transportation Research Board of the National Academies, Washington, D.C., 2010.
8. Melendez, W., and A. Horowitz. *The Transshipment Problem in Travel Forecasting: Preliminary Analysis of the Ontario Commercial Vehicle Survey.* National Center for Freight and Infrastructure Research and Education, Center for Urban Transportation Studies, University of Wisconsin, Milwaukee, 2009.
9. Melendez, W., and A. Horowitz. *The Transshipment Problem in Travel Forecasting: Tour Structures from the Ontario Commercial Vehicle Survey.* National Center for Freight and Infrastructure Research and Education, Center for Urban Transportation Studies, University of Wisconsin, Milwaukee, 2009.

The Transportation Demand Forecasting Committee peer-reviewed this paper.